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Chasing the Sun--The Inflight Evaluation of an Optical Head Tracker

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14. ABSTRACT
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Chasing the Sun-
The In-Flight Evaluation of an Optical Head Tracker

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ABSTRACT

The objective of this paper is to present the details surrounding the experimental design and flight test program used to evaluate the performance of an Optical Head Tracker (OHT) under dynamic flight and intense solar conditions. This program was a collaborative effort led by the Air Force Research Laboratory (AFRL) in close concert with NASA-Glenn Research Center (NGRC) based in Cleveland Ohio and contractors supporting the laboratory. The thrust of this paper will focus on the experimental design necessary to effectively evaluate the OHT performance, as well as safety of flight considerations necessary to satisfy both AFRL and NASA strict safety requirements. Discussions will include airborne platform selection, modification, and operations necessary to achieve maximum solar exposure on the OHT while ensuring a representative environment was presented to the OHT during the experiment.

1. INTRODUCTION

In attempting to improve the man-machine interface, the use of tracker technologies has become increasingly important by allowing the user to quickly manipulate the operational environment. Tracker technologies have been extensively applied to map human movements of whole and specific body parts in the movie and gaming industries. However in military aviation, trackers are primarily used to track pilots' head positions and orientation, enabling pilots to quickly acquire items of interest and present Fighter Data Link-type information in the modern battlespace. While maintaining hands on the throttle and control stick, a pilot is able to slew sensors and overlay applicable symbology with a simple head movement. It is faster and more intuitive to accomplish tracker-assisted weapons-slewing by simply "looking" at a target, as opposed to pointing the nose of the aircraft at the target to acquire with the head-up display (HUD) or by using a thumb wheel to slew the sensor.

2. BACKGROUND

There are many reasons that helmet-mounted trackers were not initially incorporated into early high performance fighter aircraft of the United States Air Force (USAF). A primary concern with employing head-trackers is the limitations imposed by head tracker technologies. Although there are many different head tracker technologies commercially available and under development, all have positive and negative attributes that will be reviewed in this paper. Hybrid trackers are also available and use a combination of technologies to either compensate for a deficiency or simply improve its performance. The trade-offs to a hybrid-approach is an increase in complexity and cost. A more in depth discussion of head trackers can be found in Kocian and Task's chapter.[1]

2.1 Magnetic Trackers

The Joint Helmet Mounted Cueing System (JHMCS), a magnetic tracker, is extensively employed in various fighter aircraft for applications including weapons cueing. The success of the JHMCS can be attributed to a high degree of accuracy, large motion box, and minimal additional head weight. Prior to use, magnetic trackers require the magnetic fields of the environment to be mapped so the tracker system can compensate for magnetic distortion during its solution-computation. Mapping a cockpit's magnetic field is a tedious, time-consuming task, requiring the aircraft to be removed from service for periods of time, thereby impacting the ready-rate and combat sortie generation capability of critical assets.[2]

Maintenance tasks such as changing the ejection seat or canopy frame affect the electromagnetic fields requiring the cockpit to be remapped, thereby increasing the aircrafts' down-time. A special mapper is required to meticulously measure the magnetic fields, adding to the overall system cost and logistic footprint.[2] Because of their sensitivity to metallic components, magnetic trackers are impractical for use in transport aircraft where large metal cargo items such as vehicles and weapons-toting troops are transported.

2.2 Inertial Trackers

Inertial trackers have been under development for several years and are only now maturing to a useful performance-level worthy of consideration to incorporate within an operational cockpit. A significant benefit of inertial trackers is their ability to cover the entire head box with minimal hardware. Their high update rate provides a high-degree of accuracy while reducing latency but typically require extensive data filtering. An inherent deficiency with inertial-sensors is the need for constant motion or external feedback in order to prevent drift.

2.3 Optical Trackers

Although OHT have been extensively used in military aircraft such as the Apache helicopter, there is a resurgent interest in the new Eurofighter and the next-generation aircraft. Optical trackers have many benefits that make the technology highly attractive for various applications. They are relatively simple to install, add little helmet-weight and are not subject to magnetic field fluctuation. Some general OHT limitations are the system-size, daylight/night vision goggle (NVG) compatibility as well as the number of emitters and receivers required to cover a large head box area.

Under a collaborative sponsorship from DARPA, Army, and the AFRL, Ascension Technology Inc., based in Burlington Vermont, designed and produced the phasorBIRD™ optical head tracker. This proof-of-concept system demonstrated a robust approach to answer AFRL's requirements. Vulnerability to non-system light is a concern with optical trackers since positions are calculated from the sensor-receivers view of system-light emissions. Because optical trackers transmit light to system receivers in order to determine solutions, concerns of how OHT systems might impact light-sensitive components such as NVGs exists. During static laboratory tests, the phasorBIRD™ performed very well demonstrating compatibility with NVGs. These preliminary tests confirmed system viability paving the path for testing in a more dynamic flight environment. The planned flight evaluation was not intended as a formal qualification test, but to assess the capability of the tracker in flight when exposed to full, above-the-clouds sunlight.

3. SYSTEM DESCRIPTION

The phasorBIRD™ suite incorporates sensors tuned to operate within the ultra-violet (UV) spectrum allowing tracker-functionality without affecting NVG operations. The phasorBIRD™ was particularly attractive since it utilized relatively few emitters and receivers to achieve an adequate head box size. Fewer components would theoretically translate to lower procurement and operational costs from a relatively small logistics footprint.

The system consists of eight UV-emitters mounted on two arrays that would conceptually be mounted to the sides of a helmet or head-worn device. A system of six cameras, intended to be cockpit or "dashboard" mounted would monitor the position and orientation of the flashing UV-emitters to determine a head orientated solution. The cameras and emitters were integrated by means of an electronic unit (EU) and laptop computer.

4. EXPERIMENTAL DESIGN

The test design goal was to assess the tracker's precision while operating in a realistic flight environment. *Repeatability*, as described by Parisi, "is 'how' close together a repeated set of measurements are to each other, each taken at supposedly the same point, (i.e. head orientation and position)."[2] To repeatedly measure a set of head positions, the emitters were mounted on a gimbal assembly with graduated position settings on all three rotational axes, allowing the gimbaled-tracker to return to the same position-combinations along the azimuth (AZ), elevation (EL) and roll (RL) axes for comparison.

Base-line data would be collected on the ground under minimal ambient light conditions by moving the gimbal to predetermined settings and recording the tracker's position. This process would be repeated in flight under concentrated

solar conditions. Ideally, both data sets would be the same or 'repeatable' regardless of the lighting conditions. This basic test would help determine the tracker's utility in a fighter aircraft with a large canopy transparency operating in intense-light conditions.

Parisi describes the measurement of *Accuracy* as "represented in either precision or bias. Bias, sometimes called an offset, is how close a measurement, or the average of a set of measurements, is to the actual or true value. If the item (gimbal) being measured is moved away from the point it is at to somewhere else and brought back to the exact same physical point, one would hope to get the same output value that one had before."[2]

Gimbal-position combinations were developed that would position the gimbaled-emitters from benign orientations to more extreme angles (see Figure 1). The intent was to assess the tracker's ability to accurately track 'head' positions when not all emitters were 'observed' by the receiver cameras. Camera placement would be critical for both providing system functionality as well as ensuring a representative environment was established for the test. The cameras were installed at representative camera-to-emitter distances and look-up-angles, which will be addressed later during discussion of the Test Skid Design.

With replication of UV-levels within a fighter a principle design focus, it was necessary to assess the transmissivity of UV-light through a "typical" fighter aircraft transparency. Filtering-mediums and solar intensity contribute to the duplication of the solar exposure of a fighter aircraft at 40,000ft.

Data-Point	Az-Degree	El-Degree	Rl-Degree	Data-Point	Az-Degree	El-Degree	Rl-Degree
1	-90	0	0	13	0	5	0
2	-60	0	0	14	0	15	0
3	-30	0	0	15	0	30	0
4	-15	0	0	16	0	60	0
5	-5	0	0	17	0	0	-45
6	0	0	0	18	0	0	-15
7	5	0	0	19	0	0	15
8	15	0	0	20	0	0	45
9	60	0	0	21	10	10	0
10	90	0	0	22	45	55	0
11	0	-15	0	23	45	45	0
12	0	-5	0	24	-10	-10	0

Figure 1. Gimbal Orientations

Filter Mediums

In a 'perfect' test environment, the sun's energy would beam directly and unfiltered to the tracker receivers, providing a 'worst-case' test condition. Even if this was possible to accomplish for the test, it would provide an unrepresentative environment as solar energy is diffused as it is passes through the Earth's atmospheric 'filter'. The sun's inclination from the horizon determines the air mass the light would have to traverse before reaching the aircraft, thereby affecting the level of solar attenuation.

Solar energy is further reduced as it passes through the aircraft's canopy transparency. Aircraft windscreen optical characteristics vary depending upon materials, geometry, and coatings applied during manufacturing, such as those employed for anti-abrasion, UV-filtering and stealth characteristics. Transparency materials with diverse filtering properties are utilized across numerous platforms, depending upon the desired requirements such as speed, operating altitude and stealth requirements. Optical characteristics of conventional high-performance fighter aircraft were the basis for this test.

Using a collimating tube and portable spectrometer, the UV transmission levels were measured through actual fighter canopy coupon samples with different properties to determine the target UV-intensity for the experiment (see Figures 2a-

2d). This was important in helping select an airborne platform for the test that would provide a fair system evaluation under a representative environment.

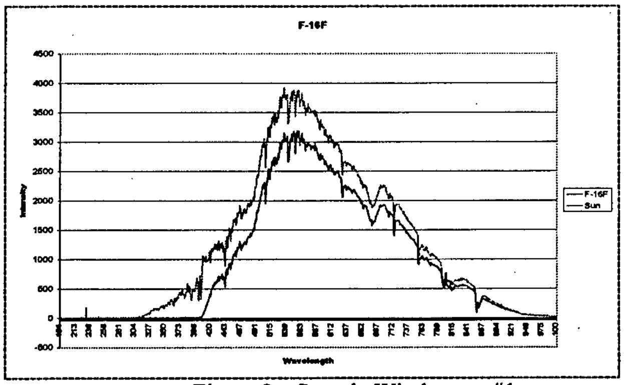

Figure 2a. Sample Windscreen #1

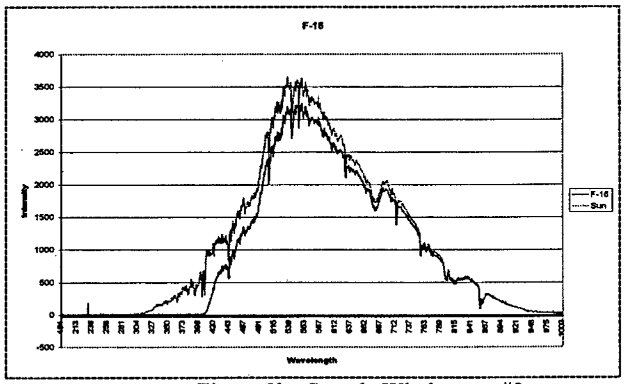

Figure 2b. Sample Windscreen #2

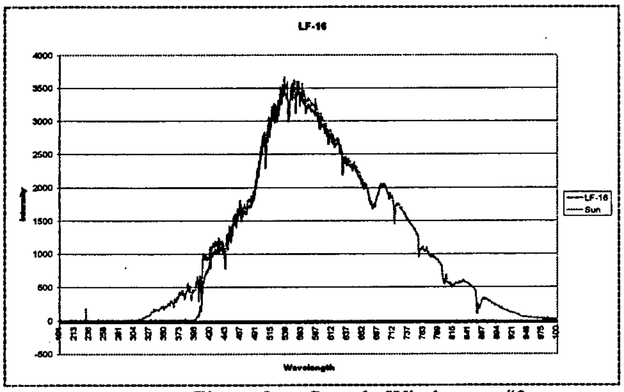

Figure 2c. Sample Windscreen #3

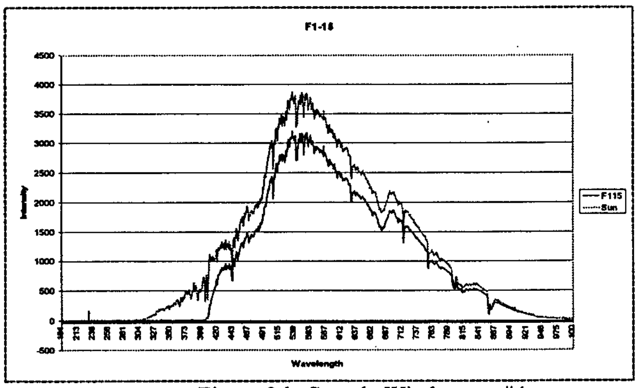

Figure 2d. Sample Windscreen #4

5. AIRCRAFT SELECTION

Several military airborne platforms were considered for the test but dismissed either due to cost, availability and/or safety of flight considerations. The limited scope of the test allowed for utilization of non-military aircraft that were more accessible and less expensive to employ than military aircraft. Selecting an appropriate aircraft to support the evaluation was paramount with typical program costs and schedule concerns. The initial focus was identifying a candidate with a windscreen of desired optical characteristics and sufficient surface to maximize solar exposure to the tracker system. Other important considerations were adequate space for the tracker system, test instruments and personnel, as well as safety-of-flight requirements. These requisites, as well as aircraft availability, quickly narrowed the selection.

NGRC was contacted about aircraft types and availability, with particular interest in the DHC-6 Twin Otter (see Figure 3). After explaining the test concepts, the research team traveled to NGRC to tour the facilities and assess the viability of using the Twin Otter. Primarily used for icing research, the Twin Otter appeared a viable option with its spacious aft compartment, instrumentation racks and relatively simple safety of flight concerns. Early test-plan concepts envisioned mounting the tracker on a large and stable gimbal placed in the right front-seat of the Otter, which would allow maximum solar exposure. NASA's safety requirements allow a single pilot to fly the Otter during non-ice study missions, which appeared a feasible option. This set-up would require the technician to move from the aft to the forward area to reposition the gimbal during data collection. The aft compartment and avionics racks were ideally located, allowing the technicians to easily conduct the experiment.

However, the cockpit lacked sufficient space to mount the gimbal assembly without limiting the flight control movements. The extremely narrow walkway between the aft compartment and cockpit would pose mobility problems when trying to make gimbal adjustments. A quick measurement of the windscreen's optical characteristics presented

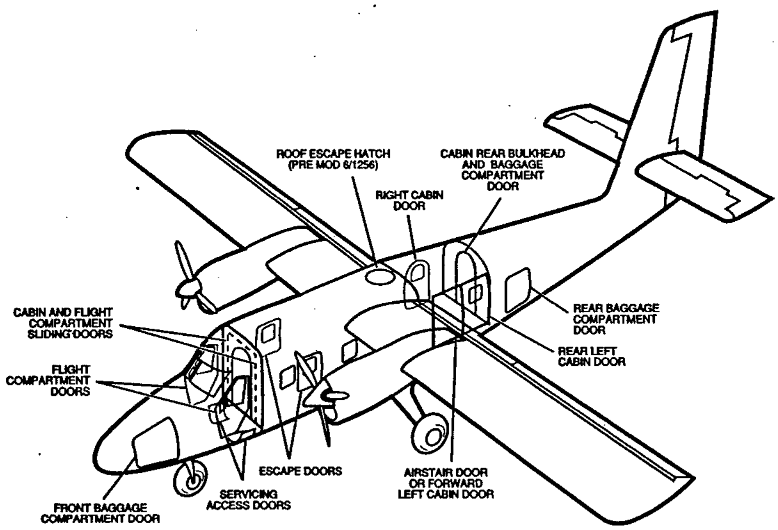

Figure 3. DHC-6 Twin Otter

additional problems as it lacked sufficient solar attenuation necessary to replicate that of a fighter aircraft. This test configuration for flying in the Twin Otter was rejected.

Other NGRC flight assets were considered, including two Lear jets whose thicker windscreens more closely emulated the desired optical characteristics. NGRC has both a Lear Jet 25 and Lear Jet 23 available for research, albeit with different flight limitations than the Twin Otter. A two-pilot NGRC safety requirement would relegate the gimbal to be located behind the pilots' seats. Although these aircraft posed potential solutions to problems presented with the Twin-Otter, they also introduced new concerns. Mounting the gimbaled-tracker in the aft compartment was not acceptable since the location would prevent adequate solar exposure. In addition, the pilots would need to fly directly at the sun at an increasing high angle of attack in order to maximize solar exposure.

The Twin-Otter was revisited to explore a new approach: to locate the test skid assembly in the aft compartment of the Twin-Otter with solar energy introduced via removal of the portside cargo doors. For safety and solar attenuation, the cargo-doors would be replaced with a transparent 'door' with appropriate optical qualities. The transparency surface would also need to be large enough to mimic the solar exposure of a fighter canopy. Unique design and safety concerns evolved with the new installation concept and the search for an appropriate transparency material began in earnest.

Concepts of using a section of an actual fighter canopy for the door-transparency were considered but the canopy-geometry made it too difficult to integrate into a safe structure. NGRC proposed two types of material for the aircraft modification. The first was an Acrylic sheet (0.240" thick) with a spectral transmission in the 380-400 nm bands. This sheet was rejected because the spectral transmission was within the camera filter pass-band and would cause system interference. A second Acrylic sheet (0.771" thick) was measured and found to more closely emulate a fighter canopy and the thickness appeared sufficiently robust to withstand mounting within the aircraft frame structure. The material was selected and delivered to the NGRC aircraft structural specialist for installation. Once installed, the acrylic sheet fully spanned the door cavity and was attached to the fuselage with aluminum angles (1"x1") bolted to the existing door hinges ensuring the support angles would cast no shadows on the OHT. The minute gap between the acrylic-window and door frame was sealed with an RTV sealant (Mil-A 46146) to minimize vibration and prevent engine exhaust from entering the cabin.

6. DATA COLLECTION

6.1 Tracker Data
Three data collection systems were utilized and synchronized through a parallel port interface on the primary system. Synchronization enabled correlation of all data points, allowing anomalies noted during analysis to be traced to particular flight conditions or events. The optical tracker served as the primary system controlling the firing of the transmitter arrays and the sampling of the camera receivers. The electronics unit controlled both the transmitters and receivers, while the laptop was used to store the individual samples.

6.2 Spectral Data
An HR2000 High-Resolution Miniature Optic spectrometer from Ocean Optics collected light readings across the band of 200-1100 nm, allowing researchers to know the spectral environment in which the tracker was performing. The sensor was mounted within close proximity to the tracker cameras and positioned at the same look-up angle as the receivers. The sampled data were transferred and stored on a laptop, which was mounted in the equipment rack.

6.3 Vibration Data
Basic aircraft performance and environmental data were necessary to model the conditions for future testing as well as post-flight data analysis. Since aircraft vibration would potentially impact the tracker accuracy, it was necessary to measure and understand the aircraft-induced vibration and compensate for this displacement during tracker performance analysis. A Remote Vibration Environment Recorder (REVER) was used to collect vibration data. The REVER is a portable battery powered vibration collection system used to collect human vibration data in military operational environments. Three tri-axial accelerometer packs were used to measure vibration at various locations on the test skid. The tracker laptop computer triggered the REVER, creating corresponding data files with both the spectrometer and tracker. In order to determine the optimum propeller settings with the least vibration, NGRC flew the Twin-Otter to Dayton for vibration profiling in order to select the ideal propeller settings for the test.

7. FLIGHT PLANNING

7.1 Solar intensity
Selecting a flight time became a paramount concern. The goal was to subject the OHT to 'typical' solar conditions experienced in a fighter aircraft, so maximizing the solar intensity radiating through the aircraft window was critical. Two interrelated flight parameters needed to be discerned: 1) What time and 2) Angle-of-Bank (AOB) to fly the test. Contributing to these issues was determining the desired sun-angle of inclination (AOI) during the test as this would influence test-skid-design as well as flight parameters.

Selecting an early morning take-off would dictate a lower AOI, as it correlates directly with the time of day. However, a lower AOI would lend both positive and negative benefits. The sun's energy would be diffused through the atmosphere at the lower AOI, as the sun's energy traveled through a larger air mass, thereby reducing the solar energy on the tracker. The positive trade-off would be that the aircraft could maintain minimal AOB during the test. A low AOB was desirable to reduce the aircraft vibration induced from high AOB flight, as well as provide a safer and more conducive environment for the technicians collecting data.

Conversely, a higher AOI would provide more direct energy, with the solar-noon providing the optimum solar conditions with less air mass for the light to traverse. However, attempting to fly the aircraft with the sun beaming in the window at solar-noon would require flying with the right wingtip pointed straight down and the portside window towards the sun overhead. Flying with this extreme sideslip would cause severe aircraft vibration, affecting the precise mounting of the test components as well as posing precarious safety conditions.

An on-line US Navy resource was utilized to calculate the sun's position relative to location and time of day.[4] These calculations helped determine the required aircraft bank angle and heading relative to local time of day (see Figures 4, 5) to maximize the solar exposure. The best case was approximately 22 degrees, but the pilot was realistically able to track to about 10 degrees without much difficulty. Anything over 15 degrees would have required flying the aircraft in a radical sideslip thereby increasing onboard vibration and increasing the pilot's workload. A primary time of 0915 was

designated to be airborne and on-station ready to collect data, with an afternoon window as a backup in the event of weather or technical problems. These periods allowed the pilot to fly with minimal AOB to keep the sun beaming directly through the window. Once on station, the pilot 'chased' the sun by either increasing or decreasing the AOB or 'sideslip'. In the morning, the sideslip increased as the flight progressed, while in the evening, as the sun sank towards the horizon, the pilot started with a sideslip that lessened as the flight progressed.

Preferential Aircraft Parameters											
Table Tilt (deg)	30.00										
	UAT	Zenith			Azimuth			Local Time	Look Up Angle	True Heading	AOB
	h m s	o	'	"	o	'	"				
2005 Sep 08	1:00:00 PM	69	58	22.2	99	48	51.4	9:00	20.0	190	-10.0
2005 Sep 08	2:00:00 PM	58	53	1.1	110	56	7.7	10:00	31.1	201	1.1
2005 Sep 08	3:00:00 PM	48	41	43.5	124	31	36.6	11:00	41.3	215	11.3
2005 Sep 08	4:00:00 PM	40	18	43.1	142	15	39.6	12:00	49.7	232	19.7
2005 Sep 08	5:00:00 PM	35	11	44	165	19	19.2	13:00	54.8	255	24.8
2005 Sep 08	6:00:00 PM	34	53	10.3	191	28	57.7	14:00	55.1	281	25.1
2005 Sep 08	7:00:00 PM	39	30	5.6	215	7	39.6	15:00	50.5	305	20.5
2005 Sep 08	8:00:00 PM	47	35	19.4	233	27	45.7	16:00	42.4	323	12.4
2005 Sep 08	9:00:00 PM	57	37	38.9	247	26	45.4	17:00	32.4	337	2.4
2005 Sep 08	10:00:00 PM	68	39	15	258	46	30.6	18:00	21.3	349	-8.7

Figure 4. Preferential Aircraft Parameters

To assist in maintaining the appropriate AOB, NGRC installed a solar scope on the dashboard of the aircraft (see Figure 6). The scope's angle was adjusted to mirror the look-up angle of the receiver-cameras mounted on the test skid (see Figure 7) enabling the pilot to 'aim' the window and OHT receiver-cameras at the sun. The scope presented a 'fireball' in the viewport when the scope was aimed directly at the sun, allowing the pilot to safely fly the aircraft while maintaining the desired flight profile.

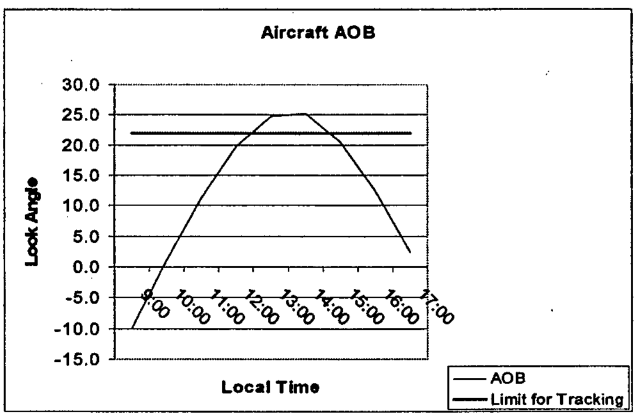

Figure 5. Aircraft Angles-of-Bank

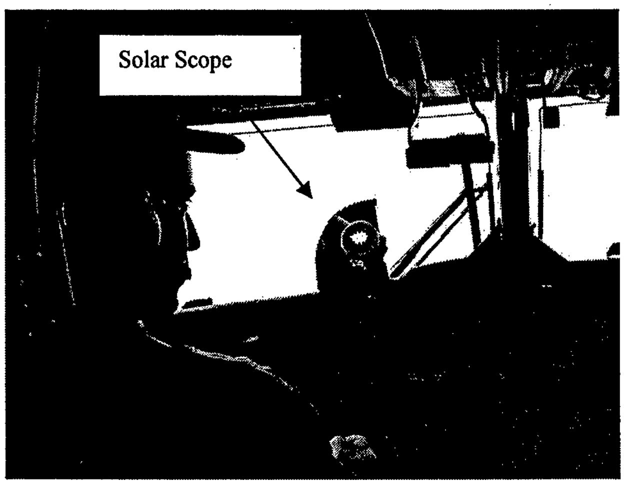

Figure 6. Solar Scope

When considering the flight altitude to collect the data, the maximum flight altitude was restricted to 9,000ft by NGRC safety regulations. Higher altitudes would be permitted if the technicians were sent to physiological altitude chamber training. With the primary spectral interest at the 365nm range, experts at NGRC determined there was not a significant

difference in UV light intensity between 9K-40K feet. The test plan was written directing data to be collected at 9,000ft feet with the caveat that flights would only be initiated when no clouds were anticipated.

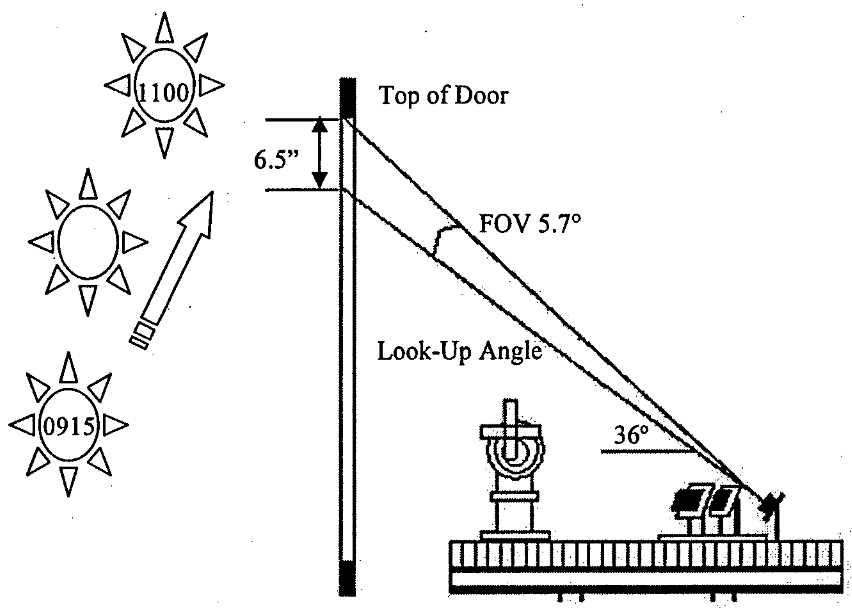

Figure 7. Camera Look-Up Angle

8. SAFETY

A risk analysis was required to mitigate potential hazards as well as satisfy requirements mandated by Safety Review Boards (SRB) at the Air Force Research Laboratory and NASA. Three window-failure scenarios were identified as potential concerns during flight operations.

1. Structural resonance of the window assembly due to engine vibrations.
2. Cracks due to thermal stress resulting from dissimilar coefficients of thermal expansion between the aluminum and acrylic.
3. Cracks due to aerodynamic loads during aircraft yaw.

After collecting performance data for the acrylic material, NGRC engineers began the risk analysis for the modifications. Vibration-profiles were factored against the structural characteristics of the acrylic to assess potential failure-conditions for the window. A displacement of 0.310" at the center of the window was determined to be the maximum tolerable deflection before structural failure could occur. The RTV sealant was factored into the analysis, anticipating potential vibration dampening benefits.

A ground run of the DHC-6 Twin Otter was conducted with the acrylic window installed. The engines were powered to 100% rpm, sweeping a wide range of torque and rpm settings in search of potential damaging resonance points, but none were found. In addition, beating frequencies were set-up between the engines resulting in low frequency vibrations between 5 and 30 Hz while alternating flap deployment from full to half settings. During these runs, noticeable forced vibrations were felt in the window, but no resonance was noted. The window behaved better than anticipated, with some benefits attributed to significant damping from the RTV sealant around the window.

Concerns for cracks in the window induced from thermal stress were quickly allayed. Calculations of thermal stress in plastic from mechanical assembly with metal brackets demonstrated no significant thermal load at the metal-plastic interface.

Aerodynamic loads on the window induced by aircraft yaw were analyzed and determined to be insignificant. A maximum yaw angle of 15° at 160 knots was assumed for the load calculations on the surface of a 15 ft^2 window. The aerodynamic load was computed to be no greater than 90 lbs and within acceptable limits on the window surface.

Because of potentially fatal repercussions, additional safety precautions were necessary to address a window failure caused by an unpredictable event. The primary concern was someone falling out of the aircraft and/or damage to the aircraft from airborne window fragments. To mitigate this risk, the researchers would be tethered to the aircraft structure when not strapped in their seats. Mobility was required to make gimbal adjustments, requiring someone to unstrap from their seat to reposition next to the floor-mounted gimbal. Retention was provided via a standard parachute-type harness and tether assembly. The modified harnesses allowed for quick attach-detach action from fuselage mounted I-bolts enabling the researchers to easily move about the cabin. The tether lengths were limited to preventing researchers from exiting the fuselage should the window fail.

Window fragments impacting flight control surfaces was another concern, should the window disintegrate in flight. Through expert engineering analysis, NGRC quickly abated the issue. NGRC predicted the likely path the window fragments would travel should the window shatter in flight. When conducting icing research, the Twin-Otter accumulates thick layers of ice that are eventually shed from the wings and other structures as part of the study without damaging the aircraft. From this experience, NGRC demonstrated the low probability of broken acrylic entering the air-stream causing significant damage to any flight control surfaces. After extensive analysis, the Twin-Otter was granted a NASA-Glenn Research Center Safety Permit, allowing the window to be used on other research projects.

9. SKID DESIGN

After selecting the Twin Otter as the test platform, design of the test fixture mount was initiated. Since the flight test was being conducted on a NASA aircraft over the course of about eight weeks, it was necessary for the fixture to be easily installed and uninstalled for each flight, allowing the aircraft to be utilized for other research. The fixture also had to be sufficiently flexible to allow quick and easy adjustments while robust enough to prevent unwanted movement during setup or flight. The cameras had to be mounted at a sufficient distance from the emitters to maximize camera field of view and oriented to view the gimbal-mounted emitters throughout the various gimbal rotations.

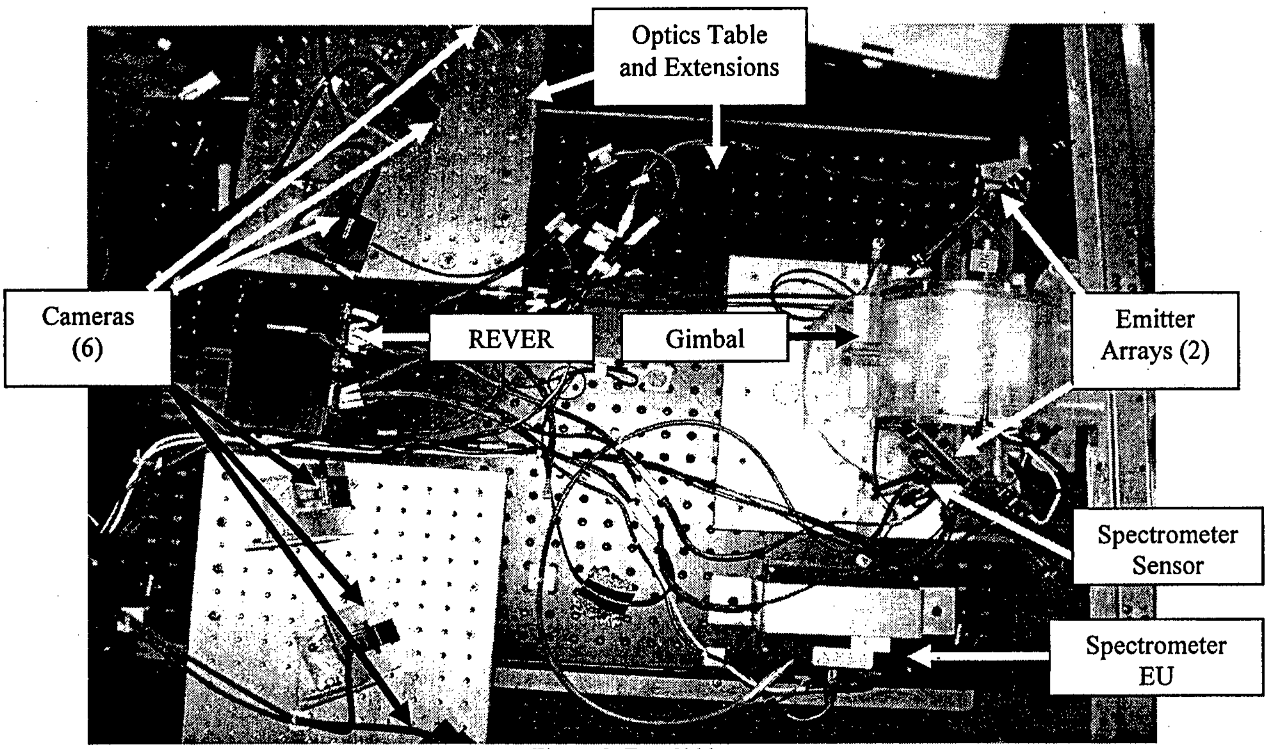

Figure 8. Test Skid

To address the quick-install requirement, a test-skid was created by mounting the majority of the test components on a portable (2' x 3') optics table (see Figure 8). The width of the optics table was expanded by mounting plates on the side to provide the proper camera-to-emitter distance. The skid was then mounted to the aircraft via parallel seat rails located between the left and right aft cabin doors. The skid provided easy removal of the test equipment and allowed all the equipment to be removed as an integral assembly.

The rest of the equipment, including two laptop computers and an electronics unit, was mounted in an existing avionics rack (see Figure 9), interconnected by a single cable bundle. The REVER and spectrometer were mounted in the open space on the skid so as to not interfere with the OHT system. Once the test setup and flight plan were defined, the benefits of raising the gimbal and cameras to a 30-degree up-look were realized. This orientation would facilitate tracking the sun without placing the aircraft in a high AOB. These changes allowed the pilot to follow the rising sun until approximately 11:30 AM without exceeding the maximum 20° AOB. Door clearance was taken into consideration, ensuring the aircraft structure did not occlude solar exposure (see Figures 7, 10).

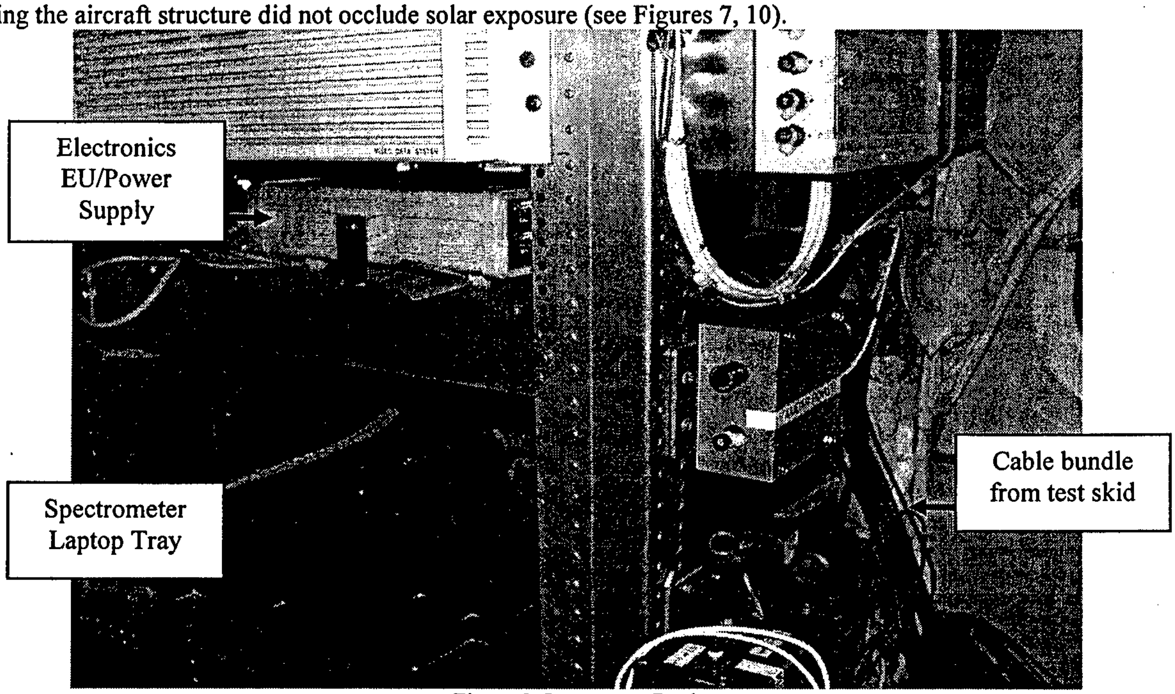

Figure 9. Instrument Rack

Stability was paramount to ensure errors were not induced by the test fixture. The cameras required brackets that could adjust in both azimuth and pitch. to allow proper alignment with the gimbal-mounted emitters. With the brackets properly oriented, it was critical to maintain their orientation regardless of vibration or incidental contact.

Another concern for the flight test was reducing propeller induced vibration since it could contribute error in the tracker calculations. To reduce the effect of vibration, isolators were installed between the skid and seat rail mounts. A survey of the aircraft's vibration profile was compiled by conducting a test flight to assess various propeller speed and torque settings, thereby identifying an ideal propeller configuration for the tests.

10. HUMAN CONSIDERATIONS

10.1 Test Subjects

Prior to conducting any experiments, consideration for the protection of human test subjects was paramount to ensure compliance with the code of federal regulations (CFR). An Institutional Review Board (IRB) is conducted by AFRL prior to any experiment involving human test-subjects to resolve potential hazards to the humans. After reviewing the test plan, the IRB issued an exemption from Human Experimentation Requirements since the test would neither measure human performance nor were the test results human-dependant as defined in CFR 32, part 219.

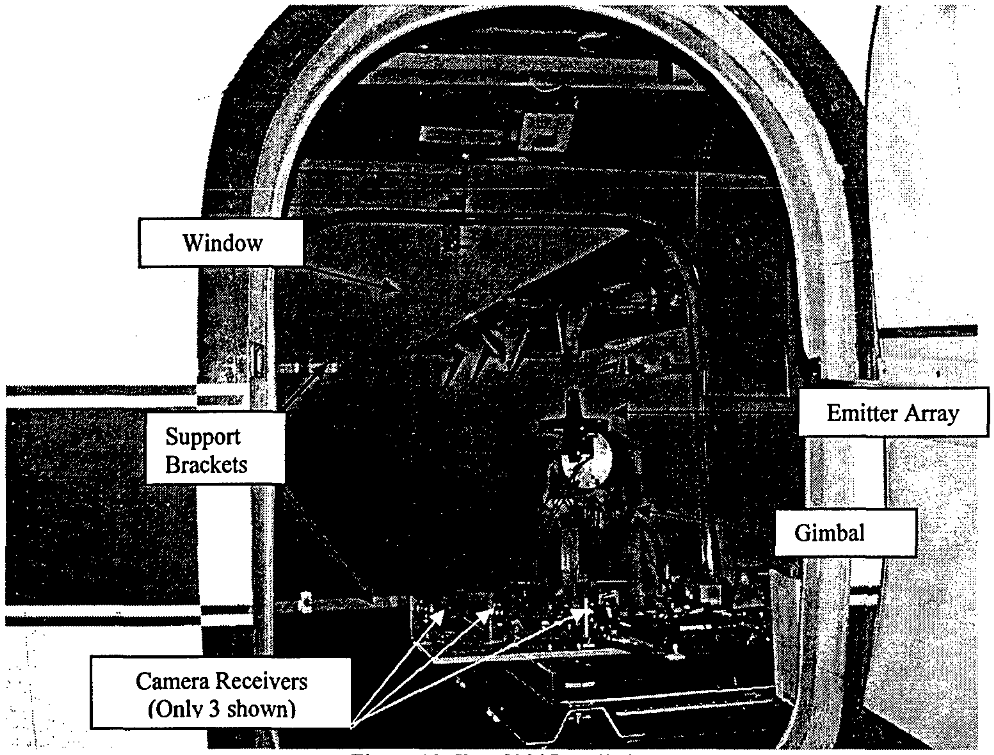

Figure 10: Test Skid Installed

10.2 Hazardous Impact

Environmental impact of any experiment is of prime concern on federal installations and requires complete consideration and approval prior to implementation. A thorough description of the test including any chemicals or hazardous bi-products is provided to the installation safety office to determine if extra precautions are necessary. Issues addressed include experimental impacts on air quality, water, biological and cultural resources. Since the experiments would not generate any hazardous components negatively impact other resources, the approval process was relatively benign.

10.3 Personal Flight Qualifications

Research personnel participating in the flight aspects of the experiment were provided a list of NGRC requirements to qualify for flight participation. Participants were required to attend physiological-effects-of-flights and egress training and pass an FAA Class III flight physical.

11. SAFETY OF FLIGHT PROCESS

11.1 Mishap Authority

With the experimental design and engineering accomplished, the program was ready to seek flight test approval. Air Force regulations determine test plan approval jurisdiction based on which agency has mishap authority. This authority is primarily based on what participating agency owns the aircraft or would be obligated to conduct an investigation should a mishap occur. Since the Twin-Otter was owned and operated by NASA-Glenn Research Center, NASA would have mishap authority and ultimately provide the final approval for the test plan with the participation of the U.S. Air Force in the safety review process.

11.2 Safety Review Board

A Safety Review Board (SRB) chairman was assigned to evaluate the test plan and provide inputs to the experimental design. An initial meeting was held with the chairman early in the experimental design to glean insight on any safety concerns with the test design concept. This was extremely valuable in formulating safety into the aircraft modification designs as well as the test plan development, ensuring safety concerns were addressed prior to convening the SRB. The actual SRB, conducted prior to the first flight, served as a formality to ensure all safety issues had been sufficiently mitigated to justify proceeding with the test.

11.3 Threat Hazard Assessments

An integral component of developing the test plan was compiling the Threat Hazard Assessment (THA) reports. The THAs identify specific safety hazards associated with conducting the experiment. Once written, the THAs would be reviewed during the formal SRB for two purposes; first, to decide if the identified hazards had been sufficiently mitigated to justify proceeding with the test and, second, to determine the approval level for the test plan. The higher the assessed threat, the higher the approval level would be. Eight hazards were noted as sufficiently significant to warrant some levels of mitigation. The majority of these hazards were easily addressed by providing protective gear for the researchers, such as protective helmets, headsets and fire-retardant flight gear. Ensuring alternate egress routes was also a concern since the portside doors would be blocked by the modified window. The hazard with the highest priority was the modified window because of the potentially fatal consequences should the window fail.

12. CONCLUSION

The in-flight evaluation of the phasorBIRD™ optical head tracker presented a multi-faceted challenge in experimental design and execution. Ensuring the tracker was tested under a realistic environment was crucial in effectively assessing the optical tracker performance for future fighter applications. A strong collaborative effort among NASA, contractor and government personnel was essential to ensuring all test and flight parameters were carefully weighed, as well as ensuring all safety of flight issues were resolved prior to flight. The tracker accuracy test results are not presented in this forum as the data are currently being analyzed, but preliminary findings indicate the phasorBIRD™ is a robust, accurate optical head tracker system that will be suitable for a myriad of airborne and ground applications.

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